Psychophysiological Response to Environmental Tobacco Smoke in an Experimental Social Setting

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Summary

Acute psychophysiological effects of environmental tobacco smoke (ETS), corresponding to carbon monoxide (CO) concentrations of 5 and 10 ppm and produced by an active smoker, were studied in 72 adult nonsmokers and compared to the effects of traffic noise (65 and 75 dB(A)) and of odorexposure (50 and 150 ppb of hydrogen sulfide). This sample represents the first block out of 126 subjects (Ss) for which data analysis was completed by November 1987. Experiments took place in an actively ventilated exposure chamber in a social setting. Objective measures, namely, heart rate, blood pressure, rate of respiration, eye blinks, and lacrymal flow as well as subjective measures of annoyance based on questionnaire items were taken four times during exposure; carboxyhemoglobin (COHb) was measured before and after exposure.

Whereas cardiorespiratory variables were not affected by ETS exposure, COHb, eyeblinks as well as part of the annoyance-data exhibited ETS-induced elevation, although not necessarily at the 5 ppm-level in each case. ETS-induced annoyance at 5 and 10 ppm dCO was comparable to noise-induced annoyance at 65 and 75 dB(A), respectively. Ss preclassified as either strongly or weakly annoyed by environmental conditions in their neighbourhoods (e.g. traffic noise or industrial odors), as assessed in a social survey covering 2,300 individuals, also did exhibit significant differential susceptibility in terms of ETS-induced annoyance. From these still preliminary findings the tentative conclusion is drawn for a no-adverse-effect-level (NOEL) for acute psychophysiological effects of ETS to be located near the 5 ppm-level in terms of dCO, and for annoyance to represent a more generalized, stable reaction-tendency rather than a reaction to a specific environmental condition.

Introduction

Most previous studies dealing with acute psychophysiological effects of environmental tobacco smoke (ETS) have used smoking machines to produce desired levels of sidestream smoke exposure (Weber et al. 1976, 1979, 1981; Muramatsu et al. 1983). In deviating from this typical procedure, which is consistent but lacks ecological validity, we conducted a pilot experiment, in which nonsmoking students were exposed to ETS by an active smoker in a social, experimentally controlled setting (Winneke et al. 1984). Objective measures, namely eyeblinks, lacrymal flow, blood pressure, heart rate and respiration, as well as subjective measures of annoyance based on questionnaire-items, were taken four times during exposure; in addition COHb-concentrations were measured before and after ETS-exosure. Significant effects of ETS-exposure were found for COHb, blinks, lacrymal flow, as well as for most of the questionnaire-based information. With

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the exception of some questionnaire-variables, exhibiting dose response-relationship, the majority of the dependent variables showed threshold-characteristics: The 15 ppm-condition only deviated significantly from the control level. From this finding the tentative conclusion was drawn for a no adverse effect-level for acute psychophysiological effects of ETS to be located between 5 and 15 ppm dCO.

In order (1) to substantiate this conclusion, (2) to compare acute psychophysiological effects of ETS to those elicited by noise- and odor-exposure, and (3) to gain information about the more specific or more generalized nature of the annoyance-response, the present extended study was conducted. The experimental part of this study, based on 126 Ss altogether, is finished whereas data-analysis is still preliminary. Partial results based on the first set of 72 Ss are given and discussed here.

Material and Methods

External Conditions

The experiments took place in a non-climatized but actively ventilated chamber with dimensions (l × w × h) 238 × 177 × 230 cm (9.7 cbm). Air exchange, as calculated from the measured dilution of H_2S in the chamber (see below) was 80 cbm/h. Two experimental subjects (Ss) and the informed experimenter who, in case of ETS-exposure, was the active smoker, were sitting in the chamber around a table playing games (Memory). Temperature and humidity in the chamber increased during the experiment, namely from about 57 to 66% (humidity) and from about 18 to 20°C on the average, irrespective of the experimental condition.

Experimental Conditions

During the experiment Ss were exposed in three counterbalanced sessions to ETS, traffic noise and odor, but at only one out of three levels of exposure. In accordance with previous work (e.g. Muramatsu et al. 1983) carbon monoxide (CO) was measured as a convenient, non-specific marker of ETS- exposure by means of non-dispersive infrared (IR-)-spectroscopy (URAS III, Hartmann & Braun, Frankfurt). CO-levels, defined as dCO by taking pre-exposure levels into account, were <1, 5 and 10 ppm, respectively. Active smoking of 0, 4.2 and 7.2 cigarettes of the same brand was necessary on the average to reach these CO-levels.

Traffic noise was presented from calibratedtape-recordings at continuous equivalent sound levels of 65 and 75 dB(A), respectively; background sound pressure-level in the experimental chamber was 60 dB(A). Spot measurements were taken at random intervals by means of a portable sound level-meter (RC 345, Reten-Elektronic, Idstein).

Odor-exposure was done by controlled metering prediluted hydrogen sulfide (H_2S) into the chamber from a pressure tank containing a calibrated gas-concentration of 100 ppm. Chamber-concentrations were set at 50 and 150 ppb and were monitored by means of the photometric molybdenum-blue method (VDI, 1974) after about 30 min sampling-time. The odor threshold of H_2S is between 1 and 3 ppb; 50 and 150 ppb correspond to perceived intensities of "distinct/strong" and "strong/very strong" according to a six-point rating-scale (Winneke et al. 1979).

Dependent Variables

Before and after each experiment capillary blood-samples were taken from a fingertip for the determination of COHb by means of gaschromatography after methane conversion; CO-concentrations were converted to COHb by means of average Hb-concentrations for males and females, respectively. At the beginning and at three consecutive intervals during the experiment (15, 35 and 55 min) systolic and diastolic blood-pressure was taken by means of an electronic device (boso digital Standard). In addition the following measures were taken continuously during the experiment but evaluated at the four regular intervals given above for two minutes duration only: Eyeblinks by means of amplified potentials recorded from one eye by means of AgCl-electrodes, rate of respiration by means of thermistor-elements attached to the nose, and heart-rate by means of photo-electric couplers attached to one ear-lobe.

In addition to these objective measures an annoyance-questionnaire was given four times during the experiment, which consisted of 39 five-point statements covering descriptive (e.g. "The air is clean"), symptom-related (e.g. "My eyes are burning"), and emotional-reactive items ("I feel relaxed"). Response-categories ranged from "Don't agree at all" to "Fully agree", or from "Not at all" to "very strong". Part of the items were specific to each of the three conditions (ETS, noise, odor), whereas others covered all three of them. This was particularly true for the emotional-reactive items, as well as for an eleven-point annoyance thermometer with response-categories ranging from 0 (not at all disturbing) to 10 (unbearably disturbing).

Subjects: 72 nonsmokers of both sexes participated. 55% of them were females, and the mean age was 44.6 years with extremes ranging from 18 to 74 years. Four Ss with initial COHb exceeding 5% were treated as suspected smokers and excluded from further analyses, thus leaving 68 Ss for final statistical evaluation. Assignment of Ss to control ($N = 23$), medium ($N = 23$), and high ($N = 22$) intensities of exposure was random.

Statistical Procedures

Both descriptive and inferential statistics were applied. Questionnaire-data were tentatively treated as being of interval-quality. Analysis of variance (mixed model) was used for the testing of main- and interaction-effects (Winer 1962). Significance-levels of 5% and lower were taken to separate significant from non-significant effects.

Results

Objective Information

CO-uptake during ETS-exposure, as given by COHb-levels, did exhibit the expected alterations (Table 1). Whereas there was a slight, insignificant decrease of COHb for control-Ss during an experimental session on the average, ETS-induced, dose-dependent increase occurred during exposure ($F = 17.3$; $p < 0.0001$). The values given in the table correspond roughly to those of the pilot-study for comparable exposures (Winneke et al. 1984), but are well below limits of biological significance (Winneke 1978).

Cardio-respiratory variables, namely blood-pressure, heart rate and rate of respiration, did not exhibit significant ETS-induced changes (Table 2). There is, however, a tendency for respiration to become slower during exposure at the highest ETS-level.

Table 1. ETS-related COHb%. Means, standard deviations (SD) and ranges are given

Groups	Before exposure			After exposure			
	$\bar{x}$	(SD)	range	$\bar{x}$	(SD)	range	N[a]
Control	0.71	(0.23)	0.58–0.84	0.68	(0.19)	0.58–0.79	14
ETS 5 ppm	0.75	(0.21)	0.66–0.84	0.87	(0.19)	0.79–0.96	23
ETS 10 ppm	0.84	(0.23)	0.74–0.94	1.03	(0.22)	0.93–1.13	22

[a] COHb-analysis of blood taken after the experiment was done in only part of randomly selected control-Ss.

Table 2. Cardio-respiratory variables. Means ($\bar{x}$) and standard deviations (SD) are given. 0, 5 and 10 correspond to levels of ETS-exposure in terms of CO

	CO	0'		15'		35'		55'	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Heart-rate	0	78.9	(8.3)	79.4	(8.5)	79.0	(8.3)	78.5	(9.0)
	5	78.1	(8.8)	78.8	(9.3)	77.2	(8.6)	76.9	(7.8)
	10	78.0	(10.4)	78.3	(10.2)	76.8	(10.3)	77.8	(11.0)
Rate of respirat.	0	18.7	(2.7)	18.2	(2.7)	18.6	(2.9)	18.1	(3.3)
	5	17.0	(3.4)	17.6	(2.8)	17.1	(2.9)	17.4	(2.5)
	10	17.7	(3.7)	17.0	(3.9)	16.5	(3.9)	15.6	(3.6)
Blood-pressure (systol.)	0	117.1	(14.6)	114.0	(13.8)	113.2	(15.6)	115.2	(19.7)
	5	130.9	(20.3)	128.7	(20.1)	129.2	(21.6)	128.1	(20.3)
	10	118.4	(21.4)	119.5	(24.4)	120.8	(28.1)	119.2	(25.9)
Blood-pressure (diast.)	0	116.9	(18.2)	111.9	(16.7)	111.4	(20.1)	114.1	(16.9)
	5	133.1	(20.6)	127.9	(18.6)	131.3	(18.6)	127.2	(21.8)
	10	121.6	(24.3)	118.2	(26.9)	116.9	(27.8)	117.9	(27.2)

The number of eyeblinks/minute increased during a one hour experimental session both under control- and exposure-conditions (Fig. 1). Comparatively, however, the rate of increase was faster at the high level of ETS-exposure than at control-level. The overall group- differences are not significant ($F = 1.92$; $p = 0.16$), although, as can be seen from the confidence-limits, the last three sampling-points of the 10 ppm-condition are significantly ($p < 0.05$) elevated. The slight elevation of the 5 ppm-curve is not significant for this sample size.

Subjective Information

Descriptive statements (e.g. "The air is clean") exhibited strong ETS-related change; typical examples are given in Fig. 2. These effects were, of course, highly significant (p <

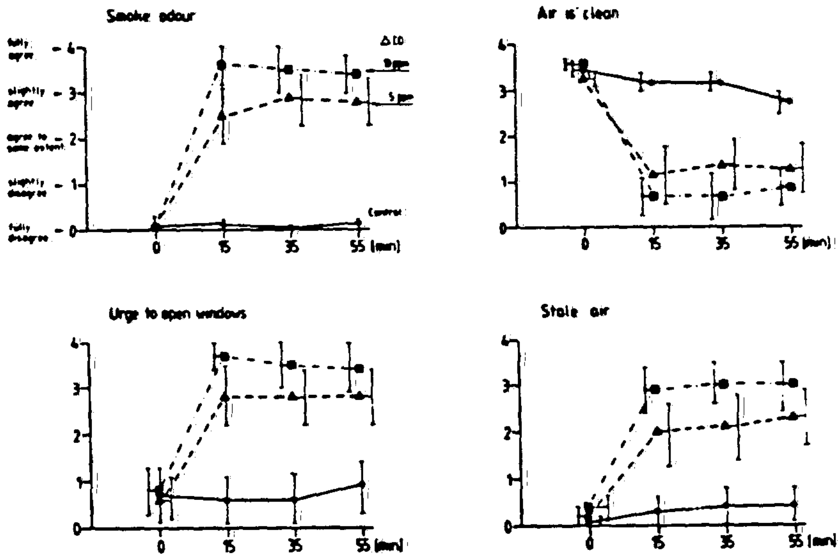

Fig. 1. Results from questionnaire-items describing the experimental situation for different levels of ETS-exposure. Means and confidence-limits (CL-95) are given

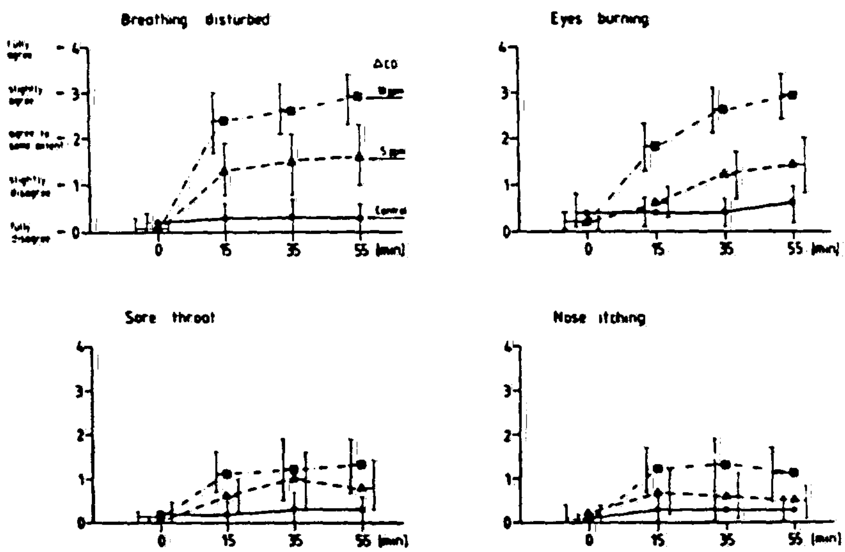

Fig. 2. Results from questionnaire-items related to perceived symptoms during different levels of ETS-exposure. Means and CL-95 are given

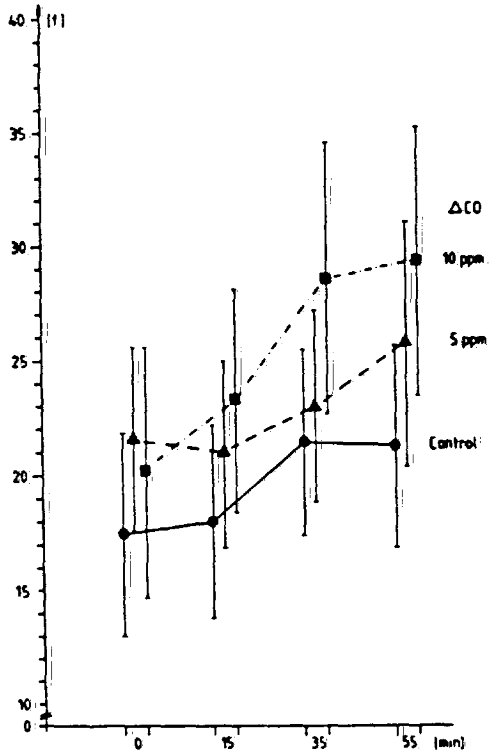

Fig. 3. Number of eyeblinks/minute during exposure for different ETS-levels. Means and CL-95 are given

Table 3. Symptom-related questionnaire-items. F- and p-values characterize the outcome of analysis of variance

	Main effect		Interaction	
	F	p	F	p
Burning eyes	19.45	0.000	20.03	0.000
Impaired breathing	19.50	0.000	14.90	0.000
Sore throat	3.43	0.040	3.84	0.001
Itching nose	4.52	0.015	2.65	0.017
Headache	1.17	0.310	2.96	0.009
Dry mouth	1.87	0.170	2.15	0.049

0.0001), both in terms of main effects (intensity of ETS-exposure) and interactions (intensity × time).

Typical examples for symptom-related effects are given in Fig. 3. The statistical results from analyses of variance for these as well as similar statements are shown in Table 3.

Table 4. Emotional-reactive questionnaire-items. F- and p-values characterize the outcome of analysis of variance

	Main effect		Interaction	
	F	p	F	p
Uncomfortable	9.26	0.000	7.50	0.000
Angry	3.93	0.024	3.42	0.003
Nervous	2.19	0.120	1.80	0.100
Cheerful	2.19	0.120	0.64	0.695
Relaxed	1.19	0.312	0.62	0.713
Merry	1.10	0.339	2.21	0.044
Concerned	0.87	0.424	1.07	0.382

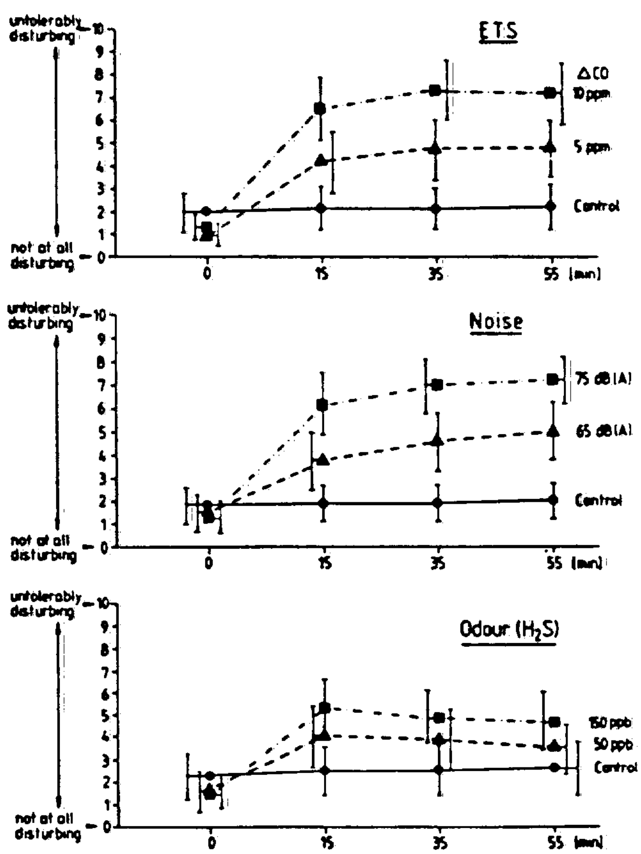

Fig. 4. Degree of annoyance during exposure to three levels each of ETS, traffic noise and hydrogen sulfide-odor. Means and CL-95 are given

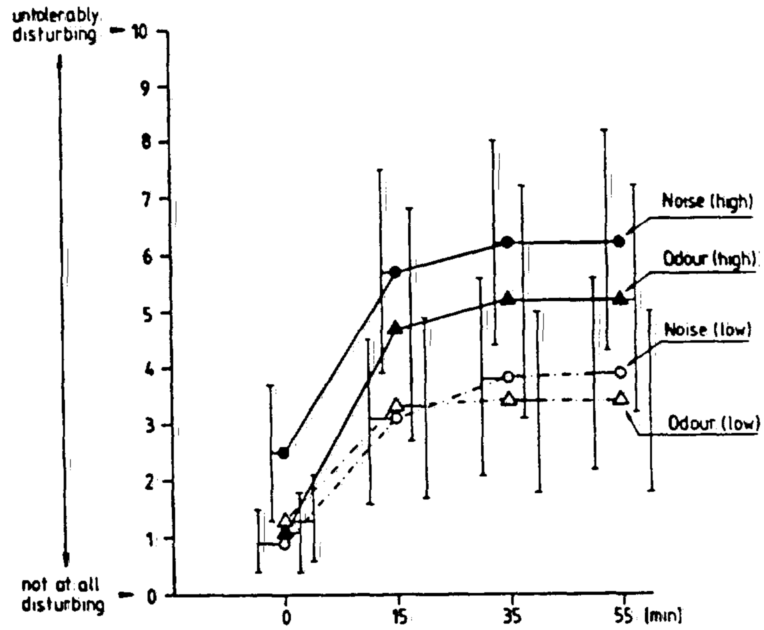

Fig. 5. Degree of annoyance during ETS-exposure for groups of Ss preclassified in terms of either high (upper curves) or low (lower curves) annoyance to environmental noise or odors, respectively. Means and CL-95 are given

Four out of eight items exhibit significant main effects (intensity), whereas for all of them significant interactions (intensity of exposure × time) were found as well. This means that the time-course is different for control- and exposure-conditions, respectively.

Only two out of seven emotional-reactive statements, namely those expressing feelings of discomfort ($F = 9.26$; $p = 0.000$) and of anger ($F = 3.93$; $p = 0.02$) did show significant main effects associated with levels of ETS-exposure, whereas additional time × exposure-interactions occurred for feelings of discomfort, anger and cheerfulness (Table 4).

For the purpose of comparing the annoying effects of ETS-exposure to that induced by either traffic noise- or odor-exposure data were taken from the eleven point annoyance-scale (see above). The results from that comparison are given in Fig. 4. These curves clearly show that for each of the three conditions highly significant ($p < 0.001$) exposure-related effects occurred which, except for the odor-condition, did exhibit pronounced dose-response-characteristics. It is interesting to note, furthermore, that the degree of annoyance produced by the two ETS-levels is roughly equivalent to continuous sound pressure-levels of 65 and 75 dB(A), respectively, whereas the degree of odor-annoyance induced by hydrogen sulfide is comparatively reduced. This, most likely, can be ascribed to olfactory fatigue or adaptation.

In order to ascertain if Ss, preclassified as either highly or weakly annoyed by either environmental noise or industrial odors in their respective neighbourhoods, these

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extreme groups were compared for degree of annoyance across exposure-levels for the three experimental conditions. Ss preclassified as highly annoyed scored higher in terms of annoyance during ETS-exposure than did Ss preclassified as weakly annoyed (Fig. 5). This group-difference is statistically significant for ETS ($F = 2.80$; $p < 0.05$), but only borderline ($p < 0.12$) for either experimental noise- or odor-exposure. Perceived intensities at the different levels of exposure did not exhibit any group-differences, whatsoever ($0.95 > p < 0.55$).

Discussion

Carbon monoxide (CO) was used here and in our previous study (Winneke et al. 1984) to characterize the degree of ETS-exposure. Both because of its lack of specificity as well as its inconsistent temporo-spatial associations with other ETS-components CO cannot be considered a truely representative marker of ETS under real-life-conditions (Ball et al. 1987), particularly if, in addition to cigarettes, pipes and cigars contribute to ETS (Klus et al. 1987). No general agreement has, therefore, been reached so far as to which components or component-combinations could be used in order to characterize ETS-exposure in natural settings.

CO, on the other hand, has been shown to display consistent association with suspended particulates (TSP), both in decay-situations as well as in experimental steady-state- or dynamic conditions, in which both the number of cigarettes as well as the rate of air-exchange were varied (Leaderer et al. 1984). In addition correlation between CO-levels on the one hand and number of cigarettes as well as several gas-phase components of ETS, such as NO, aldehydes, acrolein, HCN or formaldehyde, have been reported both for extreme (Hugod et al. 1978) as well as for more moderated degrees of experimental ETS-exposure (Weber et al. 1976).

In the light of this evidence, and in order to be able to compare the outcome of our experiment with that of similar studies (Hugod et al. 1978; Muramatsu et al. 1983; Weber et al. 1976, 1979, 1981; Winneke et al. 1984) in a quantitative manner, the measurement of CO to characterize degrees of ETS-exposure in our experimental setting can be considered a reasonable compromise between describing the true complexity of ETS-exposure on the one hand and relying simply on the number of cigarettes smoked per unit time and volume on the other.

In taking CO as the basis for comparison our cardiovascular findings are consistent with those of others (Weber et al. 1976; Harke and Bleichert 1972), who, at even higher levels of ETS-exposure did not observe exposure-related increase of either heart-rate or blood-pressure. Nicotine-intake at such ETS-levels is likely to be too low for cardiovascular changes to be expected.

As for eyeblinks our data are somewhat at variance with those of Muramatsu et al. (1983), who describe significant elevation at ETS-levels below 3 ppm dCO, whereas both in our previous (Winneke et al. 1984) and in the present study no significant increase was observed at ETS-levels corresponding to 5 ppm dCO. It is still uncertain as to whether methodological differences can explain these different outcomes. Whereas Muramatsu et al. (1983) relied on intraindividual comparisons based on actual counting of videotaped blinks by observers at predetermined intervals during exposure, our findings are based on interindividual comparisons of a smaller number of Ss by means of continuous electrophysiological recordings of spontaneous blinking. Although the latter technique would generally be considered as having a higher ecological validity, final analysis of the full set of data will be needed to clarify, if

significant elevation of eyeblinks can in fact be expected to occur at ETS-levels at or even below 5 ppm dCO.

The most clearcut findings of the present study are those related to questionnaire-based annoyance. Descriptive and, to a lesser extent, symptom-related complaints display dose-related increase with some effects already significant at the lowest ETS-level. This was not true in our previous study. Part of this differential outcome is most likely due to the fact that in the present study control-conditions were improved by forced air-exchange. From these still preliminary findings the tentative conclusion is drawn for a non-adverse-effect-level (NOEL) for acute psychophysiological effects of ETS to be located near the 5 ppm-level in terms of dCO.

The present study is the first to compare ETS-induced annoyance – reactions to those associated with either noise- or malodor-exposure. The data presented here strongly suggest that such a comparative approach is feasible, and that ETS-exposure corresponding to dCO-levels of 5 and 10 ppm are equivalent to traffic-noise at sound pressure-levels of 65 and 75 dB(A), respectively. Comparison with odor-annoyance is less convincing because adaptation strongly attenuates perceived odor-intensity for hydrogen sulfide.

Another interesting finding of the present study relates to the observation that preclassification of nonsmoking Ss for environmental annoyance is related to the degree of annoyance under experimental exposure-conditions as well: Ss preclassified as being either strongly or weakly annoyed by environmental odor- or noise-exposure in their respective neighbourhoods, do exhibit strong or weak degrees of annoyance under conditions of ETS-exposure as well. From this the tentative conclusion is drawn for annoyance-responses to be more generalized reaction-tendencies rather than responses elicited by specific environmental conditions.

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References

Ball M, Intorp M, Schilling B (1987) Measurements of ETS-components in indoor air under real life conditions. Int. Conference on "Indoor Air Quality", November 4–6, 1987 in Tokyo

Harke B, Bleichert A (1972) Zum Problem des Passivrauchens. Int Arch Arbeitsmed 29:312–322

Hugod C, Hawkins LH, Astrup P (1978) Exposure of passive smokers to tobacco smoke constituents. Int Arch Occup Environ Health 42:21–29

Klus H, Begutter H, Nowak A, Seits N, Ultsch I (1987) Measurements of ETS-components in indoor air under controlled conditions. Int. Conference on "Indoor Air Quality", November 4–6, 1987 in Tokyo

Leaderer BP, Cain WS, Isseroff R, Berglund LG (1984) Ventilations requirements in buildings – II. Particulate matter and carbon monoxide from cigarette smoking. Atm Environ 18:99–106

Muramatsu T, Weber A, Muramatsu S, Akermann R (1983) An experimental study on irritation and annoyance due to passive smoking. Int Arch Occup Environ Health 51:305–317

Verein Deutscher Ingenieure = VDI (1974) Messung gasförmiger Immissionen. Messen von Schwefelwasserstoff-Konzentrationen. Molybdän-blau-Sorptionsverfahren. VDI 2454. VDI-Verlag, Düsseldorf

Weber A (1981) Verunreinigung der Raumluft durch Tabakrauch: Grundlagen zur Beurteilung der Luftqualität und der Lüftung. Habilitationsschrift. ETH Zürich

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Weber A, Fischer T, Grandjean E (1976) Objektive und subjektive physiologische Wirkungen des Passivrauchens. Int Arch Occup Environ Health 37:277–288

Weber A, Fischer T, Grandjean E (1979) Passive smoking in experimental and field conditions. Environ Res 20:205–216

Winer BJ (1962) Principles in experimental design. McGraw-Hill, New York San Francisco Toronto London

Winneke G (1978) Grenzwertüberlegungen für Kohlenmonoxid. In: Ges. z. Förderung d. Lufthygienefoschung (ed) Med. Inst. für Lufthygiene und Silikoseforschung, Jahresbericht 1977. Giradet, Essen, 75–90

Winneke G, Kotalik J, Keldenich HO, Kastka J (1979) Zur Wahrnehmung von Schwefelwasserstoff unter Labor- und Feldbedingungen. Staub-Reinhalt Luft 39: 156–159

Winneke G, Plischke K, Roscovanu A, Schlipköter HW (1984) Patterns and determinants of reaction to tobacco smoke in an experimental exposure setting. In: Berglund B, Lindvall T, Sundell J (eds) Indoor air, vol 2: Radon, passive smoking, particulates and housing epidemiology. Swedish Council for Building Research, Stockholm, pp 351–356